can be seen in FIG. **4**, the effects on resistivity based on the grain boundary and surface scattering are high at diameters of less than 10 nm. As the diameter increases, these effects are drastically reduced. The overall resistivity is therefore reduced greatly for diameter that increases from 10 nm to over 100 nm (see, also FIG. **5**). This improvement in electrical properties must be balanced, however, against the decreased transparency for applications requiring a transparent conductor.

[0063] FIG. **6** shows a single Ag nanowire **4** that extends between two other electrical terminals **6***a* and **6***b*, to provide an electrically conductive path from terminal **6***a* to terminal **6***b*. The term "terminal" includes contact pads, conduction nodes and any other starting and ending points that may be electrically connected. The aspect ratio, size, shape and the distribution of the physical parameters of the nanowires are selected to provide the desired optical and electrical properties. The number of such wires that will provide a given density of Ag nanowires is selected to provide acceptable electrical conduction properties for coupling terminal **6***a* to terminal **6***b*. For example, hundreds of Ag nanowires **4** can extend from terminal **6***a* to **6***b* to provide a low resistance electrical conduction path, and the concentration, aspect ratio, size and shape can be selected to provide a substantially transparent conductor. Therefore, transparent, electrical conduction is provided from terminal **6***a* to terminal **6***b* using a plurality of Ag nanowires.

[0064] As can be appreciated, the distance from terminal **6***a* to terminal **6***b* may be such that the desired optical properties are not obtained with a single nanowire. A plurality of many nanowires may need to be linked to each other at various points to provide a conductive path from terminal **6***a* to terminal **6***b*. According to the invention, the nanowires are selected based on the desired optical properties. Then, the number of nanowires that provides the desired conduction path and overall resistance on that path are selected to achieve acceptable electrical properties for an electrical conduction layer from terminal **6***a* to terminal **6***b*.

[0065] The electrical conductivity of the transparent layer is mainly controlled by a) the conductivity of a single nanowire, b) the number of nanowires between the terminals, and c) the connectivity between the nanowires. Below a certain nanowire concentration (also referred as the percolation threshold), the conductivity between the terminals is zero, i.e. there is no continuous current path provided because the nanowires are spaced too far apart. Above this concentration, there is at least one current path available. As more current paths are provided, the overall resistance of the layer will decrease.

[0066] Conductive nanowires include metal nanowires and other conductive particles having high aspect ratios (e.g., higher than 10). Examples of non-metallic nanowires include, but are not limited to, carbon nanotubes (CNTs), metal oxide nanowires, conductive polymer fibers and the like.

[0067] As used herein, "metal nanowire" refers to a metallic wire comprising element metal, metal alloys or metal compounds (including metal oxides). At least one cross sectional dimension of the metal nanowire is less than 500 nm, and less than 200 nm, and more preferably less than 100 nm. As noted above, the metal nanowire has an aspect ratio (length:width) of greater than 10, preferably greater than 50, and more preferably greater than 100. Suitable metal nanowires can be based on any metal, including without limitation, silver, gold, copper, nickel, and gold-plated silver.

[0068] The metal nanowires can be prepared by known methods in the art. In particular, silver nanowires can be synthesized through solution-phase reduction of a silver salt (e.g., silver nitrate) in the presence of a polyol (e.g., ethylene glycol) and poly(vinyl pyrrolidone). Large-scale production of silver nanowires of uniform size can be prepared according to the methods described in, e.g., Xia, Y. et al., *Chem. Mater.* (2002), 14, 4736-4745, and Xia, Y. et al., *Nanoletters* (2003) 3(7), 955-960.

[0069] Alternatively, the metal nanowires can be prepared using biological templates (or biological scaffolds) that can be mineralized. For example, biological materials such as viruses and phages can function as templates to create metal nanowires. In certain embodiments, the biological templates can be engineered to exhibit selective affinity for a particular type of material, such as a metal or a metal oxide. More detailed description of biofabrication of nanowires can be found in, e.g., Mao, C. B. et al., "Virus-Based Toolkit for the Directed Synthesis of Magnetic and Semiconducting Nanowires," (2004) *Science,* 303, 213-217. Mao, C. B. et al., "Viral Assembly of Oriented Quantum Dot Nanowires," (2003) *PNAS, vol.* 100, no. 12, 6946-6951; Mao, C. B. et al., "Viral Assembly of Oriented Quantum Dot Nanowires," (2003) *PNAS,* 100(12), 6946-6951, U.S. application Ser. No. 10/976,179, and U.S. Provisional Application Ser. No. 60/680,491, which references are incorporated herein in their entireties.

[0070] More specifically, a conductive material or a conductor (e.g., a metal nanowire) can directly bind to a biological template based on an affinity between the conductive material and certain binding sites (e.g., peptide sequences) on the biological template.

[0071] In other embodiments, a conductive material can be created by a nucleation process, during which a precursor is converted to conductive particles that bind to the biological templates, the conductive particles being capable of further growing into a continuous conductive layer. This process is also referred to as "mineralization" or "plating". For example, a metal precursor (e.g., a metal salt) can be converted to an elemental metal in the presence of a reducing agent. The resulting elemental metal binds to the biological templates and grows into a continuous metallic layer.

[0072] In other embodiments, a seed material layer is initially nucleated onto the biological material. Thereafter, a metal precursor can be converted into metal and plated on the seed material layer. The seed material can be selected, for example, based on a material that causes the nucleation and growth of a metal out of a solution containing a corresponding metal precursor. To illustrate, a seed material layer containing palladium can cause the mineralization of Cu or Au. As one specific example, for creating a Cu conductor, acceptable seed materials may contain palladium, a palladium based molecule, Au or an Au based molecule. For an oxide conductor, a zinc oxide may be used as a nucleation material. Examples of the seed material include Ni, Cu, Pd, Co, Pt, Ru, Ag, Co alloys or Ni alloys. Metals, metal alloys and metal oxides that can be plated include, without limitation, Cu, Au, Ag, Ni, Pd, Co, Pt, Ru, W, Cr, Mo, Ag, Co alloys (e.g., CoPt), Ni alloys, Fe alloys (e.g., FePt) or TiO_2, Co_3O_4, Cu_2O, HfO_2, ZnO, vanadium oxides, indium oxide, aluminum oxide, indium tin oxide, nickel oxide, copper oxide, tin oxide, tantalum oxide, niobium oxide, vanadium oxide or zirconium oxide.

[0073] Any of a number of different biological materials can be used to provide the templates for creating the metal nanowires, including proteins, peptides, phages, bacteria, viruses, and the like. The techniques for selecting, forming and engineering a biological material that will couple to a desired metal or conductive material are described in U.S. application Ser. Nos. 10/155,883 and 10/158,596; both appli-